TRANSPORTATION CONTAINERS FOR ORDNANCE AND EXPLOSIVE WASTE REMEDIATION PROJECTS

by

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ABSTRACT

The U.S. Army Engineering and Support Center, Huntsville, U.S. Army Corps of Engineers is currently involved in the location and removal of on-surface and buried unexploded munitions at formerly used defense sites (FUDS). Many of these projects require on-site burial and demolition of the unexploded ordnance. It is of interest to determine if containers exist or can be developed to transport unexploded munitions from the remediation site to a remote site for disposal. These containers could be either reusable or non-reusable, would mitigate blast and fragment effects from an accidental detonation, and would reduce the likelihood of inadvertently detonating the munitions in a vehicle accident.

Southwest Research Institute (SwRI) was contracted to perform a preliminary evaluation of transportation containers for ordnance and explosive waste remediation projects. The work included identification of existing ordnance and explosives transportation containers and vehicles and preliminary evaluation of the containers for Ordnance and Explosives (OE) remediation projects.

The focus of the project was on containers typically used by bomb squads for safely handling bombs during demolition or transportation of the item. The evaluation considered the blast and fragment load capacity of the container, the blast and fragment safety provided to personnel in areas surrounding the container, transportability of the container, cost, maintenance requirements, ease of operations, availability, and other special requirements. A summary of this information is contained in the paper. It is intended to be of interest both to personnel working at OE cleanup sites and those with a general interest in containment or mitigation of the effects from small quantities of explosives.

The mention and discussion of products in this paper does not constitute an endorsement or recommendation on the part of the U.S. Government.

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1.0 INTRODUCTION

The U.S. Army Engineering and Support Center, Huntsville (USAESCH), U.S. Army Corps of Engineers is currently involved in the location and removal of on-surface and buried unexploded munitions at Formerly Used Defense Sites (FUDS). When Unexploded Ordnance (UXO) is located at a site, EOD personnel determine whether or not the round is safe. If the round is safe, it is usually transported to a remote site for disposal. If the round is not safe, EOD personnel will attempt to render the round safe, and transport it to a remote site for disposal. If the round cannot be rendered safe, it is detonated in place.

When transporting UXO, rounds are packed and transported using procedures developed for munitions in their "pristine" condition. In most cases, the history of the recovered round is not known; thus, the actual condition of the round and the potential hazards associated with the round are not certain. Therefore, two questions become apparent:

- Are the packing and transportation procedures developed for new or "pristine" rounds applicable for recovered munitions?

- During transportation of UXO, how can the safety of nearby personnel be enhanced or assured?

It is of interest to USAESCH to determine if containers exist or can be developed to transport unexploded munitions from the remediation site to a remote site for disposal. These containers can be either reusable or non-reusable, and would mitigate blast and fragment effects from an accidental detonation and would protect the munitions from being inadvertently detonated in a vehicle accident.

Southwest Research Institute (SwRI) was contracted by USAESCH to perform a preliminary evaluation of transportation containers for ordnance and explosive waste remediation projects. The work to be performed under this project included identification and evaluation of existing ordnance and explosives transportation containers and vehicles. This paper contains a brief summary of the study.

2.0 VESSELS CONSIDERED

Five general types of vessels or vehicles have been identified which could be of use to the Huntsville Engineering and Support Center. They are as follows:

- *Small total containment vessel* — An example is the containers by Dangerous Goods Management (Reference 1) which are rated for NEW up to 500 g. These containers have undergone substantial testing, and have been shown to resist internal blast and fragment loads both under normal conditions as well as when the container is subjected to extreme heat through fire. They are movable by hand or with carts. The DGM containers have also been approved by DOT in the past for special shipments. Although these containers do not have adequately high explosive capacity to contain most OE items recovered in the field, they can be effective, both in use and probably in cost, for small items and charge weights.

- *Spherical or cylindrical total containment vessels* — These vessels are approximately 2 to 6 feet in diameter and are rated for several pounds of high explosives. They can be mounted on trailers or the back of trucks. Weatherly Inc. and Nabco, Inc. manufacture such containers with diameters of 3.6 ft and 3.5 ft, respectively (Reference 2 and 3). Other containers have been designed, built and tested, but are not routinely manufactured. Typically, resistance to fragmentation effects, particularly those encountered from military weapons, has not been a primary criterion in the design of these vessels. Therefore, additional fragment mitigation may be necessary.

- *Vertical cylinders with open tops* — These containers allow venting of blast and fragments through the opening. Blast overpressures are reduced in magnitude and fragments tend to be thrown upward, thus causing less hazards than an explosion in the open. However, since the explosion effects are not totally contained, potential hazards are still present in the area around the vessel. For some sites, these hazards may be acceptable. Four manufacturers were identified: Hurds Custom Machinery, Inc., Criminalistics, Inc., Protection Development International Corporation, and Mistral Inc. (References 4, 5, 6, and 7).

- *Trailer or vehicle constructed to carry several total containment spheres or cylinders* — This type of vehicle allows for larger quantities of munitions to be transported while using the same containment systems described above.

- *Large cylindrical vessel mounted on a vehicle or trailer* — This vessel would have the capacity to contain an accidental explosion of larger quantities of explosives. Since the condition of the OE transported in the vessel is not certain, the sensitivity is not known, and, therefore, sympathetic detonation must be assumed in the event of an explosion. A vessel such as this must be designed to contain an explosion of all the explosive material inside. Mitigation of fragments must be considered with these vessels.

3.0 QUALITATIVE COMPARISON

A container used for transporting UXO must meet several requirements:

1. *Blast Load Capacity* — Containers that have the largest capacity will reduce the number of trips required to clear munitions from a site. Both blast and fragment resistance must be considered.

2. *Fragment Capacity* — What is the fragment resisting capacity of the container relative to the blast load capacity above?

3. *Blast Safety* — The container must provide adequate safety from blast overpressures to personnel in the surrounding area. It is not necessary to totally contain the blast overpressures, but pressure levels must be reduced from those produced by an explosion in the open. If a vented container is selected for further analysis, specific blast overpressure criteria will be chosen.

4. *Fragment Safety* — Munitions found at remediation sites potentially can throw fragments which could be hazardous to personnel located significant distances from the munition. A transportation container must reduce these hazards to acceptable levels. If a partially vented container is selected for further analysis, specific fragment hazard criteria will be specified .

5. *Transportability* — The transportation container will be used routinely to transport unexploded ordnance within the site or from one site to another. This could involve several trips per day. Therefore, it must be simple to move about various sites. All-terrain capability is an advantage. In addition, the container must be transportable on most roads and highways and should not be subjected to size or weight restrictions.

6. *Cost* — The transportation container should provide a good value.

7. *Maintenance Requirements* — Requirements for maintenance of the containers are considered. The objective is to identify a container which is reliable with little maintenance cost or time.

8. *Ease of Operations* — Because the vessel will be used routinely, it must be simple to use. Operations considered include placement of items within the chamber, door closure, use of mitigation material (if necessary), etc.

9. *Availability* — The vessels identified in this task are either readily available, routinely manufactured by a single company, or designed but not marketed by anyone. In general, only one or a few of each of the containers in the last set have actually been fabricated.

Table 1 summarizes the qualitative evaluation of each of the container types for the above issues. Each container type could be useful under certain conditions.

The small containment vessels such as those produced by DGM (Reference 1) are effective for munitions with small explosive weights. For these types of munitions, they provide a high level of safety for both blast and fragments. Due to their size, they are relatively easily handled. However, they are limited by their explosive capacity. In general, their capacity is much lower than what is required for transporting munitions from cleanup sites.

The explosive capacity of most of the containment spheres and cylinders are adequate to resist loads from one to a few typical munitions encountered. Except for the containers manufactured by Mistral (Reference 7), most will require the addition of shielding to protect the vessel from potentially catastrophic fragment impacts. Because this type of vessel totally contains the explosion effects, a high level of safety is provided. The cost and availability for this type of container varies. The Nabco container (Reference 3) is manufactured in the U.S., while both the Weatherly (Reference 2) and Mistral containers are produced overseas. Other containers of this type have been designed but are not routinely manufactured by a company; these containers could be fabricated by a machine shop using the design drawings and other information.

Table 1. Summary of Container Qualitative Evaluation

	Small Containment Vessel	Containment Sphere or Cylinder	Open Cylinder	Trailer with Multiple Containers	Large Cylindrical Container
1. Blast Capacity	< 500 g TNT	~ 5 - 40 lb TNT	~ 2 - 30 lb TNT	Multiples of Containment Spheres and Cylinders	~ 2 - 30 lb TNT
2. Fragment Capacity	High fragment resistance for fragments from typical low charge munitions	Steel vessels may require fragment shield	Steel vessels may require fragment shield	Steel vessels may require fragment shield	Steel vessels may require fragment shield
3. Blast Safety	High blast safety provided by total containment vessel	High blast safety provided by total containment vessel	Low blast safety due to vented blast - lower hazard than explosion in open	High blast safety provided by total containment vessel	High blast safety provided by total containment vessel
4. Fragment Safety	High fragment safety provided by total containment vessel	High fragment safety provided by total containment vessel	Low fragment safety due to fragments thrown through opening to area surrounding vessel	High fragment safety provided by total containment vessel	High fragment safety provided by total containment vessel
5. Transportability	Hand or cart transportable	Small trailer or truck mounted	Small trailer or truck mounted	Large trailer	Large trailer or truck mounted
6. Cost	$5,000 - $10,000 (estimated)	$10,000 - $100,000 +	$10,000 - $30,000	Multiples of Containment Spheres and Cylinders	Several $100,000
7. Maintenance Requirements	Clean and inspect	Clean and inspect	Clean and inspect	Clean and inspect (multiple vessels)	Clean and inspect (large vessel)
8. Ease of Operations	Hand operations	Hand operations Truck for mobility	Hand operations Truck for mobility	Hand operations Truck for mobility	Hand operations Truck for mobility
9. Availability	Routinely manufactured	Some vessels are routinely manufactured; others must be fabricated from drawings	Routinely manufactured	Some vessels are routinely manufactured; others must be fabricated from drawings; vessels mounted on single trailer	Vessels have been manufactured, but take sometime to fabricate

The open cylinder containers are relatively inexpensive; however, the open top allows shock waves to vent and high flying fragments to be projected from the vessel. This reduces the hazards around the vessel but does not assure personnel safety to those in the area. The open container will prevent hazards from high-velocity, low-flying fragments.

A trailer with multiple containment spheres or cylinders offers the same advantages as those cited above, with the improvement of additional capacity. The costs are composed of the cost of each container and the trailer cost; therefore, the costs increase proportionally to the capacity desired (assuming that the trailer cost is a relatively small portion of the total cost). As the total capacity increases, there may be some reduction in transportability due to size and weight limitations.

A large cylindrical container mounted on a trailer or a truck has a larger capacity with the convenience of a single vessel. It does provide a high level of safety for both blast and fragments (an internal fragment shield may be required). However, this type of container can be extremely expensive, and due to its size, it may be difficult to move around a clean-up site.

Based on the above information, only the containment spheres and cylinders were chosen for preliminary quantitative analysis (Section 4.0). Analysis was also performed to determine the blast and fragment hazards around an open cylinder. The small containment vessels were not considered because the quantity of explosives for which the container is rated is too restrictive. The large cylinder was not considered due to cost. The trailer with multiple containers was not analyzed because the analysis is identical to that performed for the containment spheres and cylinders; this type of container is still considered useful for transporting ordnance.

4.0 PRELIMINARY ANALYSIS AND REVIEW OF TEST DATA

As discussed above, additional analysis has been performed to provide a preliminary quantitative evaluation of containers which show potential for use at ordnance clean-up sites. Total containment spheres and cylinders were included in this analysis. In addition, the hazards associated with vented containers were estimated to provide guidance when these types of containers would be useful.

4.1 Vented Containers

Containers included in this group are as follows:

- *Hurds Custom Machinery* — double walled cylinder which is open on top. The cylinders are 5/8 inch thick high strength steel. The inside tube diameter is about 34 inches. The inner and outer tubes are separated by sand. When originally developed, the container was designed for loads from 40 sticks of 50% dynamite (one stick of dynamite has an explosive weight of about 0.25 to 0.50 pounds with a TNT equivalency of about 0.5). (Reference 4)

- *Criminalistics SID* ™ — double walled cylinder which is open on top. The outer cylinder is 1/2 inch thick welded, high-strength steel, 4 ft tall, and 4 ft in diameter. The inner cylinder is 1 inch thick welded, high-strength steel, 3 ft in diameter, and 3 ft - 8 inches tall. The container has a 20 lb explosive capacity. (Reference 5)

- *Protection Development International Corp. Bomb Transport Trailer* — trailer with basket fabricated of laminated non-fragmenting ballistic fiberglass, 50 inches across the top. This container can be used in conjunction with fiberglass bomb baskets. The

container will control the loads from a detonation of five sticks of 40% dynamite (about 0.5 to 1.0 lbs TNT) or fragments from a 2 inch pipe bomb with 1.5 lbs of black powder. (Reference 6)

- *International Association of Chiefs of Police (IACP) Design* — This design was developed by Battelle Memorial Institute for the IACP (Reference 8). The container consists of a 6 ft diameter, 0.75 inch thick cylinder with dished-flanged heads. The top head is partially vented with a 45 inch diameter opening in the head. The cylinder is protected by a 0.375 inch thick liner with sand filled between the liner and the cylinder. Sand is also placed in the bottom of the container. The container is rated for 50 pounds of 60% dynamite (about 30 pounds TNT equivalent).

- *Mistral Semi-Vented "OR" PROTECTAINERs* — partially vented cylindrical shaped containers with a dished end design and an open top. The walls and dished end use a patented compressive section which is designed to withstand contact detonation of explosives combined with fragments. They are specially designed to resist any desired charges. Currently, "OR" containers are in use to withstand 0.5 kg TNT and 1.0 kg TNT. (Reference 7)

All of the above containers are open on the top, and don't completely contain the effects produced by an explosion within. Shock waves and fragments are released from the container and are potentially hazardous to surrounding areas. The partial confinement provided by the container will reduce the magnitude of these hazards. Tests have been performed on the Criminalistics, Mistral "OR", and the IACP containers (References 9, 10, and 8, respectively). The tests on the Criminalistics and Mistral containers included blast measurements. None of the tests provided significant data on fragment hazards.

The resulting blast overpressure measurements are indicated in Figure 1. The measured pressures are compared to predicted pressures for a hemispherical surface burst and for a 4-walled cubicle with an opening in the roof (per TM5-1300, Reference 11). In all cases, the measured pressures are less than the calculated values. Note that the pressures were probably mitigated by sand over the charge in the Criminalistics container, and by a cover which partially restricts the opening of the Mistral container until the cover fails. Without this additional mitigation, the pressures are expected to be approximately equal to those calculated for the vented 4-walled cubicle.

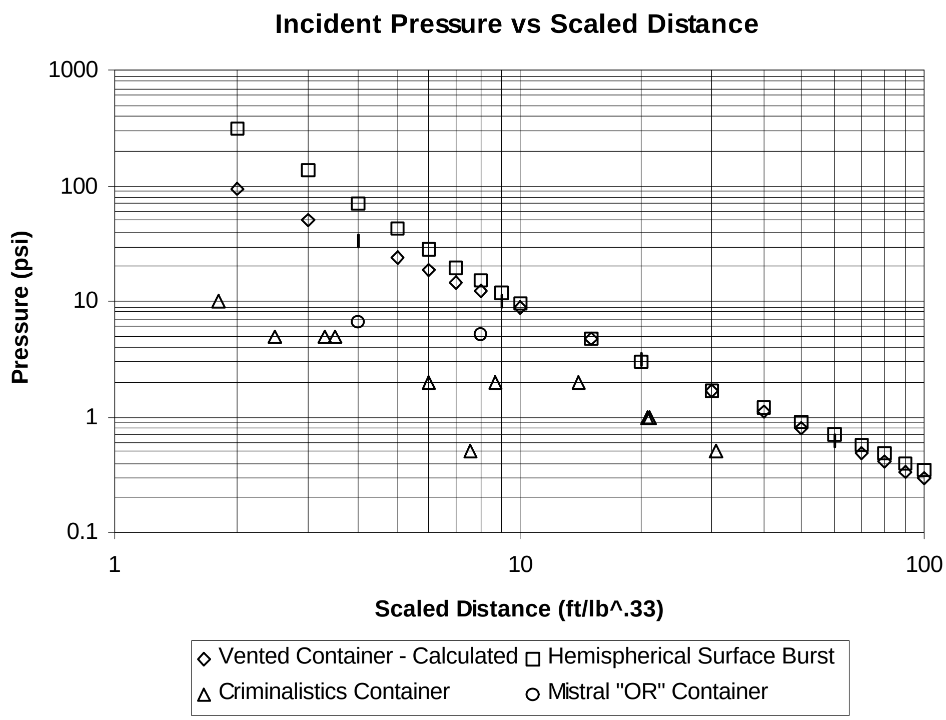

Figure 1. Calculated and Measured Blast Overpressures from Vented Containers (References 9 and 10)

With an open top container, fragments from a munition can be thrown upward and through the opening. Fragments with lower trajectories will be stopped by the container. However, fragments with higher trajectories can still be a hazard. To study the potential hazards, a fragment from a 81 mm mortar was considered with a weight of 0.068 oz, and a velocity of 6340 ft/sec. Using CONWEP, it was calculated that this fragment can penetrate 0.809 inches of steel.

Considering the container manufactured by Hurds Custom Machinery, Inc., fragments with a launch angle below 50.7 degrees will be stopped by the container. At the 50.7 degree launch angle, the selected fragment will travel 651 ft. For this same fragment in the open, the maximum distance traveled by the fragment is 877 ft for a launch angle of 20 degrees (see Figure 2 for the fragment throw vs launch angle relationship). Therefore, the container reduces the fragment throw by over 200 ft or 26%, but the maximum distance is still significantly greater than the 1.2 psi pressure contour distance which is approximately at 90 ft for 10 lb TNT and 120 ft for 20 lb TNT.

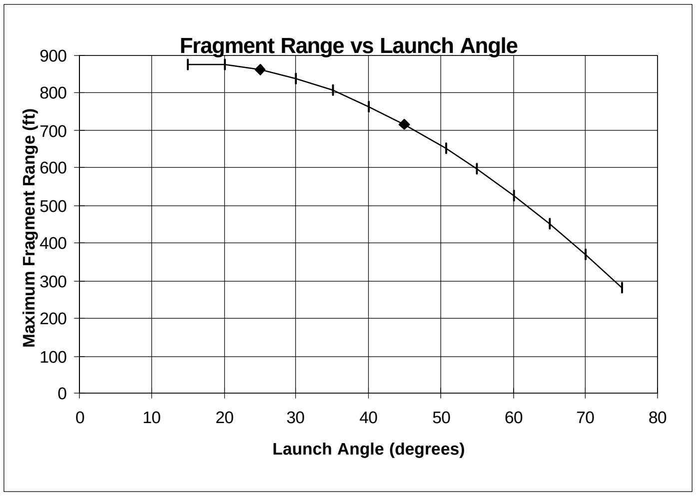

Figure 2. Fragment Range vs. Launch Angle

4.2 Containment Spheres and Cylinders

4.2.1 NABCO Container

Nabco's standard total containment vessel (Reference 3) is a 42 inch diameter spherical chamber with a 21.5 inch diameter circular opening in one side. The vessel is constructed with 1.5 inch thick HY-80 steel. The vessel is available on a trailer assembly, on an all-terrain hydraulic transporter, or prepared for installation on another vessel or trailer. The container weight is about 3500 pounds.

We performed a simple analysis of the vessel to determine the response as a sphere to predicted internal blast pressures from a 10 pound TNT explosion. Other than the use of hydrocodes, a simple procedure to calculate the loads inside a sphere is not available. Therefore, shock loads were calculated by assuming a history with 3 pulses (Reference 12). Based on these loads, the maximum radial deflection was calculated to be 0.034 inches, which gives a maximum ductility ratio of 0.77. This implies that the safety factor against yield for a single 10 pound TNT explosion is about 1.3. Note that under field conditions, loads from fragment impact could effect the response.

4.2.2 Weatherly Container

The Dynasafe MECV, Mobile Explosion Containment Vessel (Reference 2), is marketed in the U.S. by Weatherly Inc. The vessel is spherical in shape with a diameter of 1150 mm (45.3 inches). The shell is 30 mm (1.18 inches) thick steel. The vessel is formed in two halves such that the upper half pivots upward and to the side to allow access to the inside. The total weight of the vessel is about 2000 kg (4500 pounds). The vessel is mounted on a trailer, which gives a total weight of the vessel and trailer of about 2400 kg (5300 pounds). The vessel is rated for 5 kg (11 pounds) TNT.

We performed a simplified analysis of the MECV, similar to that for Nabco's TCV. For the rated 11 pounds of TNT, the maximum deflection was calculated to be 0.046 inches, which corresponds to a maximum ductility ratio of 0.77 (elastic response). This provides a safety factor against yield of 1.3 for the rated explosive quantity.

4.2.3 Mistral Containers

Mistral markets a series of portable containment chambers (Reference 7) manufactured by Koor Metal Products. The containers use a patented composite steel and compressive layer structure. The compressive layer resists penetration by fragments, absorbs the blast, and distributes the blast from off-center charges. Two containers are considered: the DROR 2 and the GOLAN 5.

The DROR 2 safely contains blast and fragments from charges up to 2.5 kg (5.5 pounds) of TNT. It is a vertical cylinder, 3.3 ft in diameter, with elliptical ends at the top and bottom. The total height of the container is about 3.6 ft from the bottom of the support to the top of the container. A sliding door is placed in the top of the container which provides a 0.84 ft by 1.67 ft opening. The total container weight is 1650 pounds.

The GOLAN 5 is larger than the DROR 2, with a capacity of up to 5 kg (11 pounds) of TNT. It is also a vertical cylinder, 6.7 ft in diameter with elliptical ends. An inward opening hinged door is placed in the cylinder wall. A clear opening of 1.67 ft wide and 2.67 ft tall is provided. The GOLAN 5 weighs about 7700 pounds.

4.2.4 Battelle Designs

During the 1970s, personnel at Battelle were involved in design, fabrication, and testing of blast containment chambers for EOD purposes. Containment spheres ranging in diameter from 2 ft to 5 ft are discussed in References 13 to 18 and summarized below.

The 2 ft diameter chamber has a nominal 0.5 inch thick wall. ASTM A-516 Grade 70 steel was used for the shell. The vessel has a 12 inch diameter port with a 2.25 inch thick ASTM A-537-72B steel door plate. The door plate seats inside the vessel, and pivots about a single point above the opening. Tests showed that the single-shot catastrophic limit is between 6.5 and 7.0 pounds of C-4.

A 3 ft diameter vessel was designed, fabricated and tested which used a 0.72 inch thick, ASTM A537 steel shell. The door plate is 1.75 inch thick ASTM A-516, Gr 70 steel and is hinged to open inward, providing a 18 inch diameter opening. During the tests, plastic deformation of the vessel did not take place until a 6.5 pound charge of special gelatin with 60% dynamite (TNT equivalency is about 0.6) was tested. Testing was stopped after a 12 pound charge was fired causing a maximum total plastic strain of 2.74%.

Two 4.5 ft diameter vessels were constructed, with one having a configuration similar to the 2 ft diameter vessel, and the other having a configuration similar to the 3 ft diameter vessel. The shell is ASTM A-537 steel with an average thickness of about 1.0 inch. The door opening has a diameter of 26.5 inches. The vessel with the hinged door (similar to the 3 ft diameter vessel) has a 1.5 inch thick mild steel door plate. The vessel with the pivoting door has a 4.0 inch thick ASTM A-516, Gr 70 steel door plate. Strain gage measurements on both vessels indicated initiation of residual strains for 3.2 pound Pentolite charges.

A 5 ft diameter, spherical blast-containment chamber was designed, fabricated, and tested for repeated detonations of 40 pounds of TNT. The shell is ASTM A-537-72A, Class 1 steel with an average thickness of 1.4 inches. An 18 inch diameter access port is provided with a pair of inward-opening "cafe-type" doors. Tests indicated that the onset of plastic deformation occurred with 20 pounds of C-4. Repeated tests (8) with 35 pounds of C-4 produced a maximum cumulative plastic strain of less than 1%. This level of response was acceptable. The authors predicted that a single detonation of 70 to 80 pounds of C-4 would produce only about 1% plastic strain, which also would be acceptable.

The containers were analyzed using a single-degree-of-freedom approach to calculate the hoop response of the sphere. These calculations are summarized in Table 2. In most cases, the calculations matched the measured response reasonably well. For the 2 ft sphere, the predicted response exceeded the measured response. As discussed in Reference 13, the designers observed the same trend. They hypothesized that the dynamic yield stress of the vessel was significantly higher than the yield stress (80 ksi versus f_y = 59 ksi), which caused a substantial increase in the dynamic yield stress. By using 80 ksi as the yield stress in our analysis, as Battelle did, the results matched very well. These strain rate effects were not as significant in the other vessels.

Table 2. Battelle Containers: Measured vs. Predicted Response

Diameter	Charge	Predicted Response	Measured Response	Comments
2 ft	6.5 lb C4	$\epsilon_{plastic} = 0.157$	$\epsilon_{plastic} = 0.0486$	$f_{dy} = f_y = 59$ ksi
2 ft	6.5 lb C4	$\epsilon_{plastic} = 0.0481$	$\epsilon_{plastic} = 0.0486$	$f_{dy} = 80$ ksi
3 ft	6.5 lb Special Gel, 60% Dynamite	$\mu = 1.2$	Elastic response	
4.5 ft	3.2 lb Pentolite	$\mu = 0.8$	At onset of plastic deformation	

4.2.5 Containment Vessel Summary

In order to provide a direct comparison of the strengths of the containment vessels considered above, the response was calculated for a single 6 pound TNT charge. The response is listed in Table 3. The Mistral containers were not included in this table.

These results show that the 2 ft diameter vessel does not have adequate capacity for typical OE identified in the field. The capacity of the 3 ft diameter vessel is marginally acceptable, but a margin for additional capacity is not provided.

Table 3. Containment Vessel Comparison

Chamber	Diameter (ft)	X_{max} (in)	μ
Nabco TCV	3.50	0.023	0.51
Weatherly MECV	3.77	0.030	0.50
Battelle	2.0	0.650	38.0
Battelle	3.0	0.056	1.81
Battelle	4.5	0.047	1.02
Battelle	5.0	0.037	0.72

Note that only the Mistral containers have an inherent protection for fragmentation effects. Both Nabco and Weatherly have a fragment shielding device that has been designed, but testing is recommended

to determine their effectiveness at resisting typical fragments encountered in the field. All of the Battelle steel containers would require the design and testing of a fragment suppression device.

5.0 SUMMARY

The focus of this study has been the evaluation of containers which could be used to safely transport unexploded munitions on or from a OE clean-up site. The primary consideration of the analysis was the safety of personnel in the vicinity of the container, which implies that the blast and fragment resistance of the container is the most important factor. Larger capacities can be provided by placing several containers on a single trailer. For further information on each of the containers, the manufacturers should be contacted directly.

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